ANALYSIS OF GROWTH IN KENNEBEC WITH EMPHASIS ON THE RELATIONSHIP BETWEEN STEM NUMBER AND YIELD

W. B. Collins

Abstract

The basis of differences in tuber yield of potato cv. Kennebec, due to varying stem numbers per plant, was studied by measuring changes in leaf-area and dry weight throughout the season. Initially the dry weight yield of tubers was related to leaf-area but following the attainment of maximum leaf-area this relationship no longer held. The final yield of tubers was shown to depend mainly on the net assimilation rate (E) late in the season. At this time E was controlled by the sink demands of the bulking tubers and these in turn were influenced by tuber number. Yields increased as the number of stems increased through one, two and four per plant-hill.

Resumen

La base las diferencias en el rendimiento de tubéculos de papa, cv. Kennebec, debido a la variación en el número de tallos por planta, fue estudiada midiendo los cambios en area foliar y peso seco durante el periodo de crecimiento. Inicialmente el rendimiento de materia seca de los tubérculos estuvo relacionado al area foliar pero después de la consecución del area foliar máxima esta relación ya no se mantuvo.

Se demos tróaue el rendimiento total de tubérculos dependió principalmente de la rata de asimilación neta (E) al final del periodo de crecimiento. En esta etapa E fue controlado por la demanda de los tubérculos por metabolitos, y esta a su vez fue influenciada por el número de tubérculos. Los rendimientos aumentaron a medida que el número de tallos aumentaba de uno a dos y a cuatro por mata de plantas.

Introduction

There is considerable evidence linking stem number in potato plants to tuber yield. Reestman and de Wit (12), for example, demonstrated that potato yields depend to a greater extent on the number of main stems per hectare than on the number of seed tubers per hectare. Bleasdale (2) concluded that both total yield and proportions of the yield in size grades were a function of the number of main stems per unit area for the varieties Majestic and King Edward. Similarly, Van Burg (14) showed that an increase in the number of main stems per hectare led to an increase in yield, and Jarvis and Shotton (7) also observed a direct relationship between stem numbers and yield.

---

[1] Research Scientist. A contribution from Agriculture Canada, Research Station, Fredericton, New Brunswick.

Received for publication April 19, 1976.

The objective of the present study was to assess the manner in which stem number relates to plant development and to yield in the potato.

Materials and Methods

The potato cultivar, Kennebec, was grown at three stem densities, one, two and four-stems per plant hill. Two-ounce (56.7 g) seed pieces were planted in 7.6 cm peat pots in the greenhouse and uniform plants were selected with the appropriate number of stems. When the plants were approximatey 10 cm in height, they were transplanted to the field in rows 91 cm apart and were spaced 25 cm apart in the row. A randomized block design was used with four replications and transplanting was done on June 8, 1973. Four samples of sixteen plants per treatment were taken weekly from June 12 onwards for growth analysis.

Methods of growth analysis (1, 4, 6) involve the calculation of various mean rates from changes in plant weights (w_2 and w_1) and leaf areas (1_2 and 1_1) observed at two sampling periods (t_2 and t_1) as follows:

mean net assimilation rate (E)

$$\bar{E} = (w_2 - w_1)(\log_e 1_2 - \log_e 1_1)/(t_2 - t_1)(1_2 - 1_1)$$

mean relative growth rate (R)

$$\bar{R} = (\log_e w_2 - \log_e w_1)/(t_2 - t_1)$$

mean relative leaf growth rate (R_L)

$$\bar{R}_L = (\log_e 1_2 - \log_e 1_1)/(t_2 - t_1)$$

To these have been added (15)

mean crop growth rate (C)

$$\bar{C} = (W_2 - W_1)/(t_2 - t_1)$$

mean leaf area index (L)

$$\bar{L} = (L_2 + L_1)/2$$

Where L and W. represent leaf area and plant weight per unit area of ground. Leaf area was calculated using the leaf disc method of Watson (15)

Results

Leaf Area Index—At first harvest (four weeks after planting) differences in leaf-area index (L) were slight (Table 1) with values for L increasing as stem number increased. The same pattern was evident for leaf area. Six weeks after planting, L values had increased markedly for all stem numbers, as had the leaf area. The largest increases occurred in four-stem plants. Eight weeks after planting, when presumably the canopy was intercepting most of the incoming radiation, L continued to increase for all stem numbers, although at a relatively slower rate. L for one-stem plants was now equal to that for four-stem plants and greater than the value for two-stem plants. Leaf area continued to be greatest in multiple-stem plants and was no longer correlated with L. Maximum values of L were reached nine weeks after planting in single-stem plants and at ten weeks in multi-stem plants. The leaf area of four-stem plants was greater than either of the other two types. L had decreased significantly for all stem numbers at twelve weeks and continued to do so until growth was terminated at sixteen weeks after planting. Leaf area behaved similarly. Decreases in both L and leaf area were slowest in single-stem plants.

TABLE 1.—*Effects of stem number on canopy development and on plant and tuber dry weight of Kennebec potato from emergence to harvest.*

Trait and stem number	Weeks from planting						
	4	6	8	10	12	14	16
Leaf area (dm^2)							
One-stem	7	71	105	143	137	131	58
Two-stems	10	80	108	138	118	98	65
Four-stems	13	95	124	153	130	105	60
Leaf-area index, L							
One-stem	0.3	3.0	5.8	6.1	5.4	4.7	2.4
Two-stems	0.4	3.4	5.4	5.9	5.6	3.9	2.8
Four-stems	0.5	4.1	5.8	6.4	5.1	4.2	2.4
Total dry weight (g)							
One-stem	5	35	110	172	200	280	282
Two-stems	7	40	115	184	219	300	343
Four-stems	10	50	118	190	228	300	350
Tuber dry weight (g)							
One-stem	–	–	10[b]	61[b]	96[b]	151[b]	202[b2]
Two-stems	–	–	28[a]	80[a]	116[a]	206[a]	260[a]
Four-stems	–	–	28[a]	81[a]	121[a]	207[a]	280[a]

[1] Values in columns followed by the same letter are not significantly different, P = 0.01.

[2] Final yields in terms of Canada No. 1 potatoes were 34.9, 45.0, and 48.9 tonnes/ha respectively for one-stem, two-stem and four-stem treatments.

Dry Weight—Plant dry weight increases throughout the growing season were greater in multiple-stem plants than in single stems (Table 1). Like leaf area, plant dry weight increases ceased to be correlated with L about eight weeks after planting or shortly after tuberization occurred. Tuber dry weights were substantially greater in multiple-stem than in single-stem plants from time of tuberization through to harvest (Table 1).

Crop Growth Rate—Crop growth rates increased initially with stem number (Table 2). The pattern of increase in C with time closely paralleled that for L in each treatment, and initial peak values for C at ten weeks after planting coincided with the attainment of maximum L values. Values for C dropped to significantly lower levels for all stem numbers two to three weeks later. The decrease in C was least in four-stem plants and subsequently these plants maintained a relatively even crop growth rate to harvest. One and two-stem plants, however, subsequently showed a second flush of growth which was followed, in turn, by a very sharp decrease in rate in the last week of the season.

The crop growth rate calculated for tuber bulking alone indicated that the tuber growth rate was distinctly greater in multi-stemmed plants than in single-stems to the time of maximum L development. Thereafter, the pattern for tubers was similar to that for the whole plant except in the case of four-stem plants where the tuber growth rate was relatively greater.

TABLE 2.—*Effects of stem number on crop growth rate (C), net assimilation rate (E), relative growth rate (R) and relative leaf growth rate (R_L) of Kennebec potato from emergence to harvest.*

Trait and stem number	Weeks from planting						
	4	6	8	10	12	14	16
C (g m^{-2} wk^{-1})							
One-stem	15	50	130	148	75	154	5
Two-stems	25	55	125	145	66	179	55
Four-stems	30	69	133	160	100	105	120
E (g $m^{-2}wk^{-1}$)							
One-stem	74	54	51	27	14	31	2
Two-stems	70	53	49	30	11	38	16
Four-stems	72	55	48	25	18	22	34
R (g g^{-1} wk^{-1})							
One-stem	1.20	1.05	0.68	0.30	0.10	0.15	0.01
Two-stems	1.05	0.95	0.63	0.30	0.08	0.17	0.06
Four stems	1.11	1.00	0.57	0.24	0.12	0.13	0.10
R_L (dm^2 dm^{-2} wk^{-1})							
One-stem	1.00	1.10	0.65	0.08	–0.10	–0.04	–0.23
Two-stems	0.98	1.02	0.55	0.06	–0.07	–0.01	–0.22
Four-stems	1.06	1.06	0.50	0.06	–0.05	–0.11	–0.23

Net Assimilation Rate—The net assimilation rate (E) for plants of all stem numbers dropped with time from the first sampling to the 12-week sampling except for a brief recovery about six weeks after planting coincident with tuberization which was occurring on plants in all treatments (Table 2). (Levels of E at five weeks, not shown, were slightly lower than those at six weeks). Differences in E to twelve weeks among stem numbers were slight. Sharp increases in E subsequently occurred in one and two-stem plants followed by an equally sharp decline just prior to senescence. E in four-stem plants increased less sharply than in one and two-stems but was still increasing when growth was terminated. Following the attainment of maximum values, the observed patterns for E, C and R in each treatment were very similar.

Relative Growth Rate—In the four and six week samplings, plants of all stem numbers were growing rapidly and doubling in size each week (Table 2). Single-stem plants were putting on the most growth. In subsequent samplings, the relative growth rate (R) dropped sharply and steadily with time until twelve weeks after planting when the growth rate was about 10% per week. At this point, R for four-stem plants levelled off and remained fairly constant to harvest. R for one and two-stem plants recovered briefly and then dropped again just prior to senescence. Interstem differences in R were generally small.

Relative Leaf Growth Rate—Initially leaf growth was doubling in area each week (Table 2). Following tuberization, however, the relative leaf growth (R_L) dropped sharply and after eleven weeks new leaf growth was not sufficient to replace losses due to senescence.

Relative Tuber Growth Rate—The calculated relative growth rate for tubers (R_T) indicated that the rate of tuber bulking increased sharply following tuberization and tended to level off coincident with the attainment of maximum canopy development about 10 weeks after planting (Table 3). Tuberization on four-stem plants was more advanced than on the other treatments and R_T values through the season were generally greater in multi-stem plants.

TABLE 3.—*Effects of stem number on relative tuber growth rate (R_TQ) and tuber number of Kennebec potato from emergence to harvest.*

Trait and stem number	Weeks from planting						
	4	6	8	10	12	14	16
R_T (g g^{-1} wk^{-1})							
One-stem	–	–	0.06	0.14	0.11	0.12	0.17
Two-stems	–	–	0.07	0.17	0.12	0.14	0.24
Four-stems	–	–	0.08	0.16	0.12	0.15	0.20
Tuber number							
One-stem	–	–	9.6	9.2	8.8	8.0	7.2
Two-stems	–	–	13.6	11.0	10.6	9.8	8.8
Four-stems	–	–	14.0	12.0	12.0	11.6	11.2

Tuber Number—The initial number of tubers set by two-stem and four-stem plants was higher than the number of tubers per hill found in single-stem plants (Table 3). The number of tubers per hill matured by single-stem plants was very little less than the number originally set, but this was not the case with two-stem and four-stem plants where tuber numbers dropped significantly from time of tuberization. The greatest decrease occurred in the three-week period following tuberization. The final number of tubers matured per hill increased as the number of stems increased.

The weight of tubers per hill increased steadily over the season (Table 1) with two-stem and four-stem plants having significantly greater weights of tubers than single-stem plants. However, the average weight per tuber differed little among stem numbers.

Discussion

Inter-stem differences in dry weight yield of tubers at harvest appeared not to be related to the rate at which leaves developed early in the season, nor to the leaf-area index in the latter part of the season. In fact, the rate of leaf growth throughout most of the season was lower in two-stem and four-stem plants than in the less productive single-stem plants. The same situation applied when the relative growth rate was calculated on the whole plant basis. Dry matter production was related to leaf-area only up to a period six or seven weeks after planting or just after tuberization. Maximum leaf-area indices were reached subsequent to this and it was apparent that as the full canopy developed, the relationship between dry matter production and leaf-area disappeared.

The largest inter-stem differences in crop growth rate occurred in late August - early September, when leaf-areas were much reduced; these differences appear to have been caused by differences in the net assimilation rate. The pattern of changes in E with time was similar to that observed by Moorby (10). The increase in E at time of tuber initiation has been observed previously by Bremner and Taha (3) and Gifford and Moorby (5). By way of explanation, Moorby (10) has suggested that the late season increase in E could be explained by noting that the dominant factor controlling the rate of photosynthesis in potatoes is the rate of tuber growth; and that a uniform rate of tuber growth can be maintained only if there is no variation in the supply of assimilates to the tubers. Sale (13) similarly concluded that assimilation is dependent on the number of developing tubers which provide a sink for the photosynthate. Thus, E would be expected to decrease while leaf-area was increasing, and at the time of maximum leaf-area or shortly afterward, would have to increase again as leaf-area decreased. Only in this way would a constant supply of assimilates be provided to the developing tubers.

Results of the present study support this hypothesis to the extent that minimum values of E were observed shortly after maximum values of L were attained. Moreover, subsequent increases in E coincided with decreasing values of L under the field conditions encountered in these studies. It was noteworthy, too, that extremes in E occurred in one-stem and two-stem plants, but that variations in E in four-stem plants were more moderate and the production of assimilates much more uniform. The results indicate also that the initial increase in rate of tuber growth immediately following initiation peaked at approximately the same time as L, and, while there were variations in rate thereafter, they were small in magnitude until the very end of the season. Milthorpe (8) and Radley (11) observed that tubers reached their maximum growth rate shortly after initiation and maintained it fairly constantly despite changes in L, so long as L exceeded a critical value.

The crop growth rate for tubers in the present study indicated that tuber bulking was consistently greatest in two-stem and four-stem plants compared to single-stem plants. Part of this was obviously due to a slightly higher rate of tuber growth in the former. Milthorpe and Moorby (9) concluded that the two or three weeks following the onset of initiation were critical in determining final yield in the U.K. If so, the observed differences in growth rate between 6 and 10 weeks may have had a significant effect on final yield. A large part of inter-stem differences in tuber yield may have been due also to differences in tuber number among stem numbers, although Bremner and Taha (3) concluded that increase in tuber number did not affect sink strength. It was evident, also, that two-stem and four-stem plants set a significantly greater number of tubers than did single-stem plants. A number of the original set in each stem number were later apparently resorbed, particularly in two-stem and four-stem plants, but significant differences in tuber number among stem numbers persisted until harvest. Inter-stem differences in the average weight of tuber proved insignificant.

In summary, differences among stem numbers in final yield of tubers depended mainly on E late in the season. At this time E appeared to be controlled by the sink demands of the bulking tubers which in turn were influenced considerably by the number of tubers per plant. Four-stem plants, as compared to single-stem plants, and to a lesser extent two-stem plants, set more tubers and provided assimilates to the growing tubers at a more uniform and efficient level of E.

Literature Cited

1. Blackman, V. H. 1919. The compound law and plant growth. Ann Bot (Lond) 33: 353-360.
2. Bleasdale, J. K. A. 1965. Relationship between set characters and yields in main crop potatoes. J Agric Sci 64: 361-366.
3. Bremner, P. M. and M. A. Taha. 1966. Studies in potato agronomy. I. The effects of variety, seed size and spacing on growth, development and yield. J Agric Sci 66: 241-252.
4. Briggs, G. E., F. Kidd and C. West 1920. A quantitative analysis of plant growth. II. Ann Appl Biol 7: 202-223.

5. Gifford, R. M. and J. Moorby. 1967. The effect of CCC on the initiation of potato tubers. Eur Potato J 10: 235-238.
6. Gregory, F. G. 1917. Physiological conditions in cucumber houses. Cheshunt Expt and Res Stn Annu Rep 3: 19-28.
7. Jarvis, R. H. and F. E. Shotton. 1968. Population studies with Majestic potatoes in rows and in beds. Exp Husb 16: 73-93.
8. Milthorpe, F. L. 1963. Some aspects of plant growth. An introductory survey. In The growth of the potato. Proc 10th Easter School Agric Sci Univ Nott London. Butterworths. pp 3-16.
9. Milthorpe, F. L. and J. Moorby. 1967. The growth of the potato. Proc 3rd Trienn Conf Eur Assoc Potato Res, Zurich 1966: 51-70.
10. Moorby, J. 1970. The production, storage and translocation of carbohydrates in developing potato plants. Ann Bot (Lond) N.S. 34: 297-308.
11. Radley, R. W. 1963. The effect of season on growth and development of the potato. In. The growth of the potato. Proc 10th Easter School Agric Sci, Univ Nott London. Butterworths. pp. 211-220.
12. Reestman, A. J. and C. T. de Wit. 1959. Yield and size distribution of potatoes as influenced by seed rate. Neth J Agric Sci 7: 257-268.
13. Sale, P. J. M. 1973. Productivity of vegetable crops in a region of high solar input. II. Yields and efficiencies of water use and energy. Aust J. Agric Res 24: 751-762.
14. Van Burg, P. F. J. 1967. Relation of rate of nitrogen fertilization, seed spacing and seed size to yield of potatoes. Neth Nitrogen Tech Bull 4: 30 pp.
15. Watson, D. J. 1958. The dependence of net assimilation rate on leaf area index. Ann Bot (Lond) N.S. 22: 37-54.